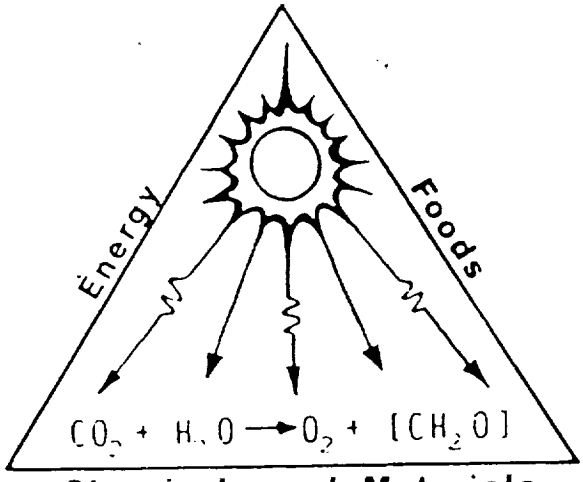
BIOSOURCES DIGEST



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PRINCIPLES, EQUIPMENT, AND OPERATION OF TWO LABORATORY SCALE BIODIGESTERS

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ABSTRACT

The major factors influencing the rate and efficiency of biogas production are briefly discussed. These variables include type of substrate, carbon to nitrogen ratio, temperature, pH, agitation, influent solids concentration, and organic loading rate.

Two laboratory scale biodigesters are described in detail. One system is a simple, batch biodigester with a water displacement gas collector. The second system uses an anerobic filter technique which can reduce the overall digestion time of fresh plant material up to 75%.

INTRODUCTION

Biogas refers to gas containing a high percentage of methane produced by the microbial degradation of organic material in the absence of oxygen. This gas also contains carbon dioxide and small amounts of nitrogen, hydrogen sulfide, and hydrogen. Biogas can be generated from a variety of substrates from animal and human waste to crop residues and green plants. The method of microbial degradation is similar for all the different organic substrates that are amenable to this natural process.

Fresh organic material that is fed into an anaerobic digester is first attacked by facultative microorganisms which enzymatically hydrolyze the polymers, mainly cellulose, hemicellulose, lipids, proteins, and sugars, into simple, soluble organics. These facultative microbes can use free and chemically bound oxygen, thereby removing the atmospheric and dissolved oxygen from the digester which inhibits or prevents the growth of the strict anaerobic bacteria. Next, the acid-forming bacteria convert the soluble organics into organic acids, primarily acetic acid. The organic acids are substrates for the last set of bacteria known as the methanogenic bacteria. The methanogenic bacteria ferment the organic acids to methane and carbon dioxide. These bacteria can also reduce carbon dioxide to methane using formate or hydrogen gas which is formed in small quantities during the acid-forming stage.

FACTORS INFLUENCING BIOGAS PRODUCTION

The rate and efficiency of anaerobic digestion is influenced by a number of factors. The most important paramters are the type of substrate, the carbon to nitrogen ratio, temperature, pH, agitation, organic loading rate, and influent solids concentrations. The impact that each of these parameters has on the anaerobic digestion process is discussed by Singh[1] and the National Academy of Sciences.[2] A brief guideline for each of these factors is listed below.

1. Type of substrate

The facultative and acid-producing bacteria must hydrolyze the polymers,

mainly cellulose and hemicellulose, into simple sugars and monomers in order for the methanogenic bacteria to complete the last step of the digestion and produce methane. Another major component of plant material is lignin which is nonbiodegradable. High lignin content reduces the available cellulose by protecting the cellulose from bacterial degradation. Therefore, high lignin content in the potential substrate results in poor biogas and methane production due to reduced availability of the cellulose.

2. Carbon to nitrogen ratio

Most raw materials contain adequate amounts of nutrients for complete digestion. If the starting substrate is deficient in a nutrient, it is usually nitrogen. The optimal C:N ratio is 30:1. A higher ratio will slow the process, and digestion will be incomplete. Digestion will proceed normally at a lower ratio; however, some nitrogen may be lost during the digestion and reduce the nitrogen content of the remaining sludge.

3. Temperature

Anaerobic digestion proceeds most efficiently in two temperature ranges: mesophilic, 33^{o}-38^{o} and thermophilic, 54^{o}-60^{o}C. The temperature should not be allowed to fluctuate suddenly or digestion will either slow down or even stop. Temperature control is especially important in the thermophilic range.

4. pH

The pH of a balanced digestion process will naturally stay between 6.6 and 7.6. The optimal pH range is 7.0 to 7.2. If the system is upset and the pH drops, usually by introducing new substrate too fast and causing the acid-forming bacteria to produce excessive acid and inhibit the methanogenic bacteria, lime may be carefully added until the pH and buffer system is restored to normal.

5. Agitation

Minor agitation is desirable, especially with vegetable matter in order to

prevent scum build-up and prolonged settling of the heavier material on the bottom.

6. Influent solids concentration

An optimal solids range of 7 to 9% is desirable.

7. Organic loading rate

This paramter is important in continous feed digesters in order to prevent an acid imbalance in the system. No general guide is available since the organic loading rate is dependent on several variables, especially the type of substrate, solids concentration, pH, and temperature. An example, for guidance, is the recommended loading rate for standard municipal digesters: 0.48-1.6 kg per m^3 per day.

LABORATORY BIODIGESTERS

I. Batch Biodigester

Simple laboratory batch digesters can be easily set up to evaluate the digestibility and methane production of various organic substrates. The system described in this paper was used by Wolverton *et al.*[3] to produce methane from water hyacinths (*Eichhornia crassipes*). The complete experimental set-up is shown in Figure 1. The system consists of a container for the substrate and a water displacement system to collect the biogas. All of the digestion equipment is incubated in a controlled temperature chamber maintained in the mesophilic range at $36^{o}\pm 1^{o}C$.

The substrate should be chopped or blended in order to provide the bacteria with a large substrate surface area. The amount of water that is added to the system depends on the inital solids content of the substrate and the volume needed to disperse the bacteria. In the first experiments with water hyacinths, a 1:1 mass ratio of water to fresh plant material was used. The substrate should be inoculated with a mixture of facultative and anaerobic bacteria before sealing the substrate vessel. An initial bacterial inoculum can be prepared from a fresh slurry of cow manure or from a slurry of the substrate that has previously been allowed to anaerobically digest for several weeks. After the first successful anaerobic digestion,

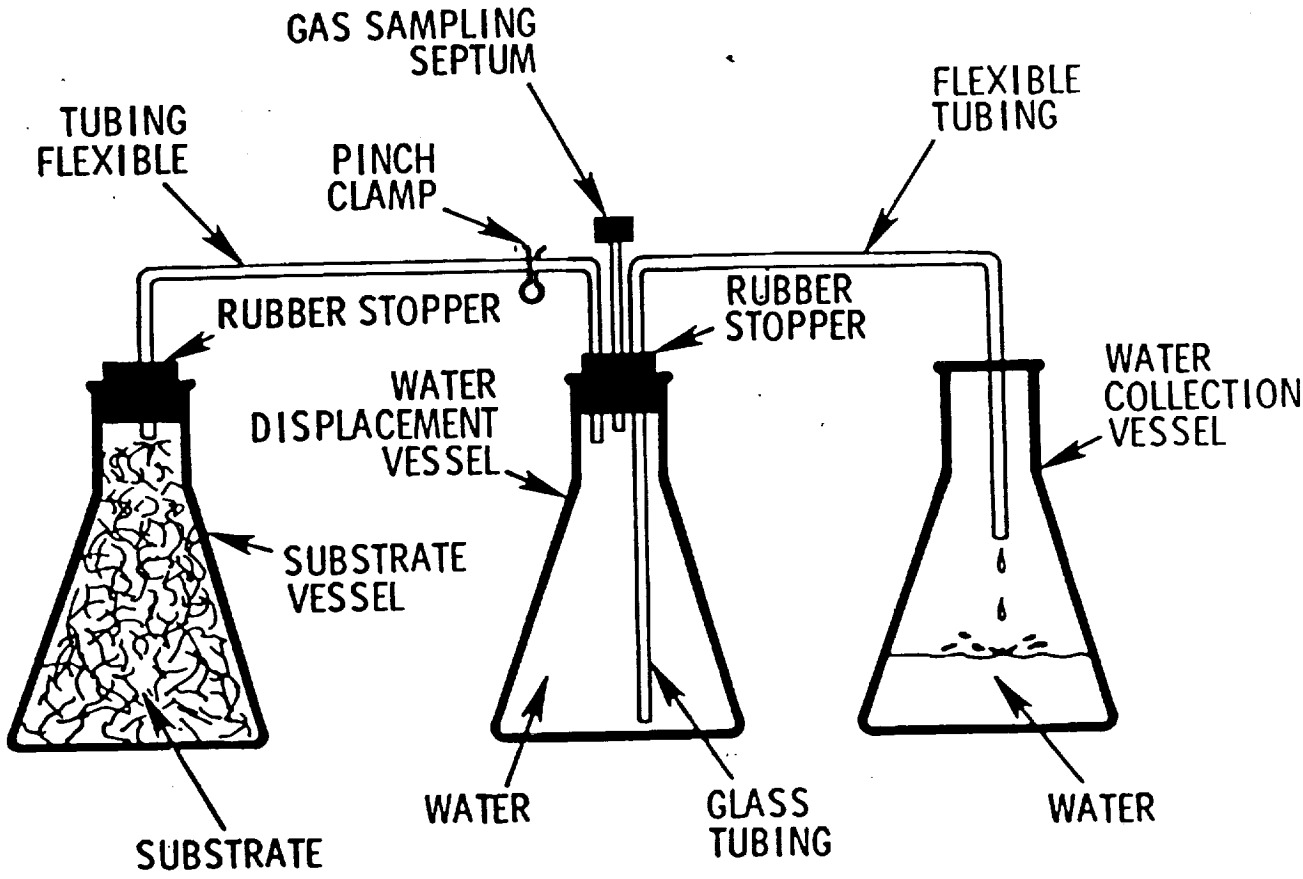

Figure 1. Laboratory Batch Bio-Digester

approximately one fourth of the remaining sludge and supernatant should be saved to inoculate the next experiment. Great care should be used to minimize the exposure of the saved material to oxygen because anaerobic bacteria are extremely sensitive to oxygen. Oxygen can suppress the anaerobic activity or even kill a large percentage of the bacterial population and cause a delay in the initiation of the next anaerobic fermentation.

After all the substrate, water, and inoculating bacteria have been thoroughly mixed in the substrate vessel, the vessel should be tightly sealed to the atmosphere. If a large dead air space is left in this vessel, it is preferable to purge the air space with an inert gas such as nitrogen to minimize the time required for the facultative bacteria to use up all the free oxygen. Batch digestion of animal wastes generally requires three weeks; whereas, digestion of plant material requires up to three months.

The water displacement system should also be completely filled with water prior to sealing it and connecting it to the substrate vessel. The pinch clamp is left loose until needed to close off as close as possible the connecting tubing to the gas collection vessel in order to minimize the introduction of air into the substrate vessel. The volume of total biogas produced is measured by the volume of water displaced, corrected for temperature and pressure. Sparks, flames, and heat sources should be carefully avoided when refilling the gas collector. Methane is highly explosive when mixed with air.

Scrubbing systems for cleaning up the biogas can be installed in the system if desired. Passing the biogas through lime water and then iron filings prior to collection will reduce the carbon dioxide and hydrogen sulfide content, respectively. Hydrogen sulfide removal is especially desirable in large gas collectors made of metal since H_2S is corrosive. If water vapor removal is desired prior to burning, a drying system containing calcium chloride may be included in the outlet line.

II. Anaerobic Filters

A new biodigestion system is currently being evaluated by Wolverton and McDonald.[4] This system shown in Figure 2 has a substrate vessel, anaerobic filter (reaction chamber), and water displacement gas collector. This system is still in the experimental stage, and the substrate preparation, flow rates, etc. are being varied in order to optimize the efficiency of this system.

The initial substrate is prepared in several manners. One method involves blending the plants with a minimum volume of water. Another method uses only the juices obtained with a squeeze press, designed and constructed by Dr. Larry Bagnall, University of Florida. A third method uses both the separated juices and solids obtained with the press.

The juices from the substrate vessel are circulated via a peristalic pump through the anaerobic filter which is a large vessel filled with small rocks. The rocks provide a large surface area for the bacteria to grow and come in contact with the substrate. After anaerobic digestion is initiated in the filter, the filter is never exposed to the atmosphere and continues to maintain a high anaerobic bacterial population that is used from digestion to digestion. Results from this system indicate that the average total digestion time is reduced to approximately 21 to 28 days even with fresh plant material.

GAS ANALYSIS

Methane alone can be analyzed using a gas chromatograph with a flame ionization detector. A six foot column packed with Porapak Q 150-200 mesh will give good results.

Nitrogen, carbon dioxide, oxygen, and methane can be analyzed with a dual column gas chromatograph fitted with a 2-channel thermal conductivity detector. The first 6'x¼" column packed with di-2-ethylhexylsebacate (DEHS) on 60-80 mesh Columpak separates the CO_2 from all other components. The second 6½'x3/16" column in series is packed with 42-60 mesh Molecular Sieve 13X and absorbs the CO_2 and

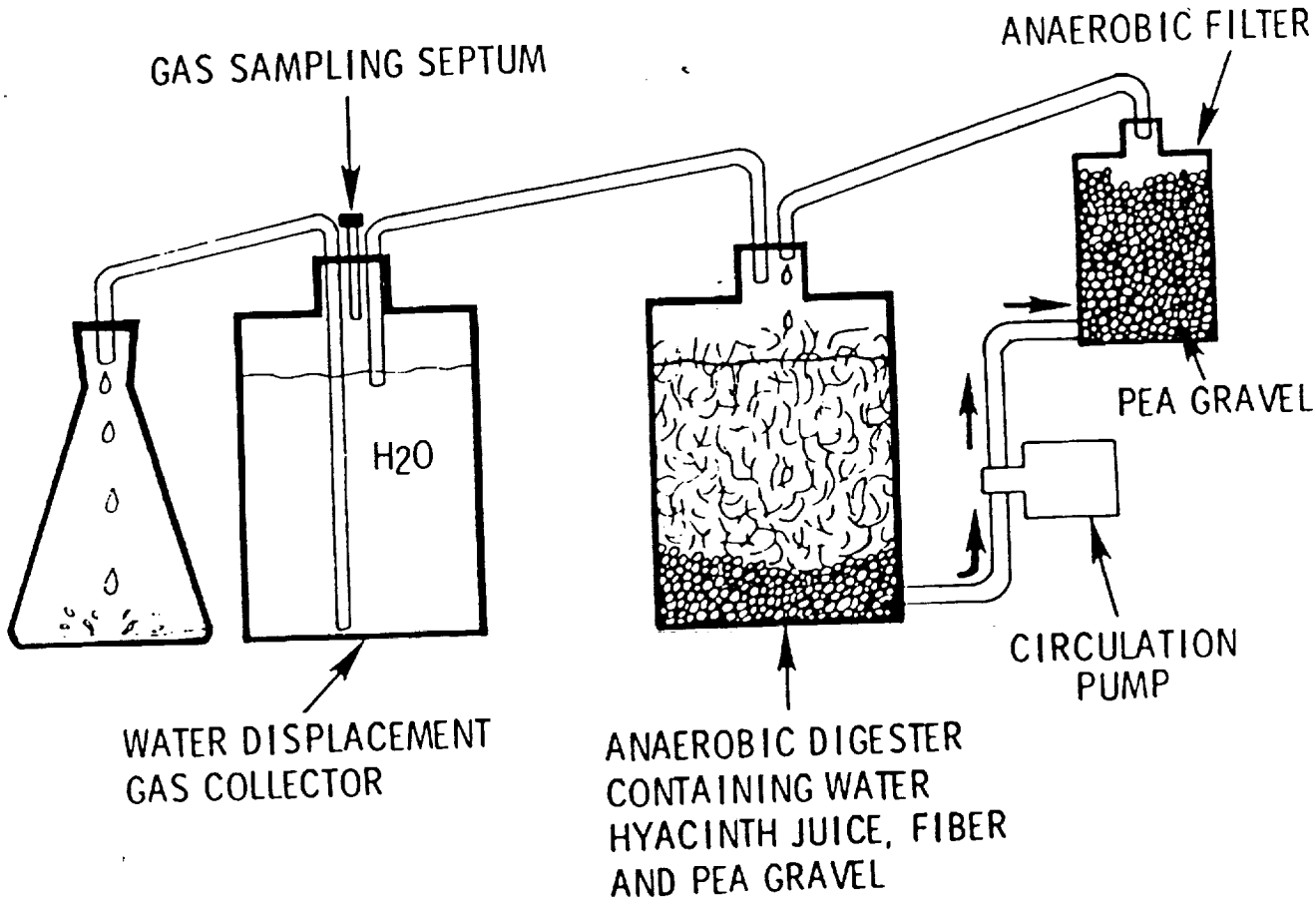

Figure 2. Two-Stage Anaerobic Digester System for Producing Methane from Water Hyacinths.[4]

separates all other major gas components. Small gas chromatographs that are especially adapted for this purpose are commercially available.

PLANT ANALYSIS

Procedures for analyzing the initial substrate and final sludge can be found in the A.O.A.C.[5] Nitrogen, phosphorus, potassium, carbon, moisture, ash, volatile solids, and fiber are the important parameters which are normally monitored. Volatile acid formation through the digestion process can be followed using the analytical procedure outlined by Etzel and Pohland.[6]

SUMMARY

Far more elaborate biodigesters than described in this paper are available. The simple biodigesters that have been outlined here can be assembled from standard laboratory equipment. These laboratory models can be easily modified to vary different parameters in order to determine the optimum conditions for a particular substrate of interest.

A large assortment of substrates from the more common ones such as municipal sludge and animal wastes to agricultural products and wastes have been investigated. New substrates receiving current interest include the water hyacinth, kudzu, and marine algae (giant kelp). All of the substrates under consideration must have high potential annual productivities in order for the microbiological conversion of the organic material to methane to be economically attractive.

More detailed accounts of the microbiological processes, equipment, and operational considerations can be found in the suggested reading.

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